



REC'D 11 MAY 1999

WIPO PCT

# Kongeriget Danmark

Patent application No.: 0551/98

Date of filing: 21 APR 1998

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0551/9821 APR 98

21. april 1998

Ny dansk patentansøgning

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Novel food-grade cloning vectors and their use in lactic acid bacteria

Vor ref: 21030 DK 1

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## NOVEL FOOD-GRADE CLONING VECTORS AND THEIR USE IN LACTIC ACID BACTERIA

### FIELD OF INVENTION

The present invention relates to the field of lactic acid bacterial starter cultures and in particular there is provided a food-grade vector comprising a nonsense mutation suppressor-encoding gene which vector, when it is present in a lactic acid bacterial strain, permits such a strain to have an industrially appropriate growth rate and metabolic activity.

### TECHNICAL BACKGROUND AND PRIOR ART

Lactic acid bacteria are used extensively as starter cultures in the food industry in the manufacturing of fermented products including milk products such as e.g. yoghurt and cheese, meat products, bakery products, wine and vegetable products. *Lactococcus* species including *Lactococcus lactis* are among the most commonly used lactic acid bacteria in dairy starter cultures. However, several other lactic acid bacteria such as *Leuconostoc* species, *Pediococcus* species, *Lactobacillus* species and *Streptococcus* species are also commonly used in food starter cultures.

A significant role of lactic acid bacteria is to render the fermented products microbiologically stable and to improve the taste and palatability of these products. It is generally recognized that genes, the expression of which are important to ensure that the addition of lactic acid bacteria to a starting material results in the desired fermentation effect, are found naturally or can be inserted on extrachromosomal DNA vectors including plasmids.



However, DNA vectors may be unstable, resulting in their loss from the cells. Accordingly, it is of pertinent industrial interest to provide vectors which are stably maintained in lactic acid bacterial starter cultures.

5 Presently used methods of stably maintaining (stabilizing) vectors in a host cell include insertion of relatively large DNA sequences such e.g. antibiotic or bacteriocin resistance genes into the cell. In the art, such genes are also referred to as selection markers. However, it is well-known that, the  
10 insertion of large DNA sequences involves the risk that other sequences are deleted from the vector. Furthermore, the use of resistance genes for maintaining the plasmid in the host cell implies that antibiotics or bacteriocins must be present in the cultivation medium. This is undesirable in the manu-  
15 facturing of food and feed products. In addition, it is undesirable that live bacteria comprising antibiotic resistance genes are present in food products as such genes may be transferable to the indigenous gastro-intestinal microflora.

Consequently, there have been reported several attempts to  
20 develop so-called food-grade cloning vectors. In the present context, the term "food-grade" indicates that the vector consists essentially of DNA of lactic acid bacterial origin.

WO 91/09131 discloses a vector essentially consisting of lactic acid bacterial DNA wherein a gene coding for the  
25 bacteriocin nisin is used as a selectable marker. However, the selection of such a vector still requires that a selective compound is added to the cultivation medium.

As an alternative approach, it has been suggested to use vectors carrying a gene coding for a gene product that sup-  
30 presses nonsense mutations in lactic acid bacteria.

In the *in vivo* synthesis of proteins occurring in the ribosomes, mRNA is translated into polypeptide chains. However, the mRNA codons do not directly recognize the amino acids that



they specify in the way that an enzyme recognizes a substrate. Translation uses "adaptor" molecules that recognize both an amino acid and a triplet group of nucleotide bases (a codon). These adaptors consist of a set of small RNA molecules known as transfer RNAs (or tRNAs), each of which is only 70 to 90 nucleotides in length. Such tRNA molecules contain unpaired nucleotide residues comprising a CCA triplet at one end of the molecule and, in a central loop, a triplet of varying sequence forming the so-called anticodon that can base-pair to a complementary triplet in the mRNA molecule, while the CCA triplet at the free 3' end of the molecule is attached covalently to a specific amino acid.

The three nucleotide triplets UAG (amber codon), UGA (opal codon) and UAA (ochre codon) do not code for an amino acid. These signals termed stop codons or "nonsense" codons, are involved in polypeptide chain termination. During translation, two protein factors (R1 and R2) recognize these triplets and effect release of the polypeptide chain from the ribosome-mRNA-tRNA complex.

Occasionally a mutation occurs in a cell resulting in a nonsense codon appearing within a gene, causing premature chain termination and the production of a protein fragment. Such fragments rarely have enzymatic activity.

The effect of such a nonsense mutation can be reversed or suppressed by a second mutation in a gene coding for a tRNA which results in the synthesis of an altered tRNA molecule. Such an altered tRNA recognizes a nonsense codon and inserts an amino acid at that point in the polypeptide chain. The mutated tRNA-encoding gene is termed a suppressor gene and the altered nonsense mutation-suppressing tRNA which it encodes is generally referred to as a nonsense or termination suppressor. Such termination suppressors may be derived by single, double or triple base substitutions in the anticodon region of the tRNA.



Most mutations in a tRNA-encoding gene leading to the formation of a nonsense suppressor are located in the anticodon triplet and alter it to CUA, UUA or UCA. Such suppressors may be referred to as amber, ochre and opal suppressors, respectively. Following the rules of nomenclature of Demerec et al., 1966 which was suggested for termination (nonsense) suppressors in *E. coli* the symbol "sup" and assigned capital letters as gene designations, e.g. *supB*, *supC* or *supZ*, are used herein also to designate suppressor genes in lactic acid bacteria.

In Dickely et al. 1995 and WO 95/10621 are disclosed plasmids containing a gene coding for a tRNA that is a suppressor for a nonsense mutation where the suppressor gene will function as a selectable marker when the nonsense mutation in the host strain for the plasmid is one which, in the absence of a corresponding suppressor gene, will render the host strain incapable of growing in a particular environments, such as e.g. milk or other food or feed products. The genes coding for suppressor tRNA are small and can be inserted without causing deletions of desired genes. Also, homologous recombination will not occur between *supD* and the chromosomal tRNA genes due to the small size.

The construction of the vector pAK89.1 that comprises a *supD* suppressor is described in Dickely et al. 1995 and WO 95/10621. However, this cloning vector contains a gene coding for erythromycin resistance and thus is not a food-grade vector.

Dickely et al. 1995 and WO 95/10621 disclose food-grade vectors based on the *Lactococcus lactis* derived nonsense suppressor, *supB*, as a selection marker. However, these vectors, pFG1 and pFG1.1, cause growth inhibition when present in host cells. It has also been found that these particular vectors, when present in lactic acid bacterial strains, are unstable and that the acidification rate of the host cells in milk is reduced as compared to wildtype strains and



therefor these vectors are not suitable in industrial processes.

Accordingly, the prior art is not aware of nonsense suppressor containing food-grade vectors that are stably maintained in lactic acid bacterial strains and which does not adversely affect the growth and metabolic activity of the host strains.

The present invention provides a food-grade vector, comprising as the selection marker a nonsense suppressor gene. It was surprisingly found, that the vector, when it is present in a lactic acid bacterial strain comprising a nonsense mutation suppressible by the suppressor, substantially does not cause growth inhibition and permits the strain to acidify milk at essentially the same rate as that of the same strain not containing the vector.

#### SUMMARY OF THE INVENTION

Accordingly, the present invention relates in a first aspect to a recombinant vector consisting essentially of lactic acid bacterial DNA, the vector comprising a gene coding for a tRNA comprising an amber suppressor and a replicon making the vector capable of replicating in a lactic acid bacterium, the vector having at least one of the following characteristics:

(i) when it is present in *Lactococcus lactis* strain FA4-1-1 deposited under the accession No. DSM 12086 having an amber mutation in the *pyrF* gene that is suppressible by the suppressor, it permits said strain to grow at 30°C at a doubling time of at the most 100 minutes in a minimal medium not containing pyrimidine sources; and/or

(ii) when it is present in a strain of *Lactococcus lactis* FH CY-1 that has an amber mutation in the *pyrF* gene (strain CHCC 4146, DSM 12109), said amber mutation being suppressible by



the suppressor, it permits the strain to acidify milk under identical conditions at essentially the same rate of that of the parent strain (FH CY-1) deposited under the accession No. DSM 12087;

- 5 and/or (iii) it permits the *Lactococcus lactis* FA4-1-1 strain (DSM 12086) to grow at 30°C in a minimal medium not containing pyrimidine sources at a doubling time which is less than that for the *Lactococcus lactis* strain DN209 transformed with the vector pFG1.1 deposited under the accession No. DSM  
10 12088, the pFG1.1 vector comprising a gene coding for a suppressor that is capable of suppressing the nonsense mutation in the DN209 strain, the transformed DN209 strain growing under conditions identical to those for the FA4-1-1 strain.

15

The present invention also pertains to a lactic acid bacterium comprising a vector according to the invention, the lactic acid bacterium possibly comprising an amber mutation being suppressible by the nonsense amber suppressor.

- 20 In a further aspect, the invention relates to an isolated pure culture of a lactic acid bacterium according to the invention, to a composition comprising such an isolated pure culture, and a carrier, and to the use of such a composition as a starter culture in the preparation of a product selected  
25 from the group consisting of a starter distillate, a product for cheese flavouring, a food product and a feed product.

- In one interesting aspect, the invention relates to a method of stably maintaining a vector according to the invention in lactic acid bacterial host cells growing in a particular  
30 environment, comprising providing said host cells as nonsense mutant cells having lost the capability of growing in said environment, and transformed with a plasmid according to the invention containing a nonsense suppressor gene encoding a gene product restoring the capability of the nonsense mutant  
35 cells to grow in said environment whereby, if the plasmid is



lost from the lactic acid bacterial cells, the cells will not grow.

#### DETAILED DISCLOSURE OF THE INVENTION

Thus, it is an important objective of the present invention  
5 to provide a recombinant vector consisting essentially of  
lactic acid bacterial DNA, the vector comprising a gene  
coding for a tRNA comprising an amber suppressor and a repli-  
con making the vector capable of replicating in a lactic acid  
bacterium and having at least one of the characteristics (i)  
10 to (iii) as mentioned above.

As used herein, the term "vector" is used interchangeable  
with the terms "recombinant vector", "cloning vector" and  
"expression vector", and relates to any DNA molecule that  
acts as an intermediate carrier into which a gene or a DNA  
15 segment is inserted for introduction into bacterial or other  
cells for amplification. Such intermediate carriers include  
DNA fragments or subsequences, plasmids, cosmids,  
bacteriophages and transposons.

When used herein, the term "lactic acid bacterium" designates  
20 a group of bacteria having as a common characteristic the  
capability to produce lactic acid from sugars. The majority  
of the species belonging to this group can be characterized  
as gram-positive, catalase-negative, microaerophilic or  
anaerobic bacteria which may be cocci or rods. The anaerobic  
25 genus *Bifidobacterium* is also generally included in the group  
of lactic acid bacteria.

The recombinant vector according to the invention consists  
essentially of DNA of lactic acid bacterial origin including  
DNA isolated from vectors or other replicons having the  
30 lactic acid bacterium as their natural host organism. In the  
art, such vectors are, as it is mentioned above, also  
referred to as being "food grade" vectors, since it is gen-



erally considered that the use of such vectors may be allowable by relevant governmental authorities for use in food manufacturing.

In the present context, the expression "amber mutation" relates to a mutation in a cell resulting in the nonsense codon UAG appearing within a coding sequence of a gene resulting in premature chain termination. The effect of such amber mutations can be reversed or suppressed by an "amber suppressor" i.e. a tRNA comprising an altered anticodon, CUA, which only recognizes amber mutations and which is the result of at least one change of nucleotide in a gene coding for a tRNA anticodon (Eggertson et al., 1988).

As mentioned above, one characteristic of the vector of the present invention is that it, when it is present in *Lactococcus lactis* strain FA4-1-1 (DSM 12086) having an amber mutation in the *pyrF* gene that is suppressible by the amber suppressor, permits said strain to grow at 30°C at a doubling time of at the most 100 minutes in a medium not containing pyrimidine sources. In preferred embodiments the vector permits the above strain to grow at a doubling time of at the most 95 minutes such as at the most 90 minutes including at the most 85 minutes.

It will be understood, that an amber mutation in a *pyr* gene of a lactic acid bacterial cell causes the cell to lose its capability to grow in a medium, like e.g. milk, which does not contain pyrimidines. Such an auxotrophic mutant will only be able to grow in the absence of pyrimidine precursor if the vector of the present invention is present in the host cell. Thus, the amber suppressor restores the capability of the cell to grow in such a medium.

As it is also mentioned above, it is of industrial interest that a vector according to the invention, when it is present in a lactic acid bacterial strain does not cause any substantial growth inhibition of the host strain. Thus, the vector,



when it is present in the *Lactococcus lactis* strain CHCC4146 (DSM 12109), permits this strain to acidify milk at essentially the same rate as that of the same strain not containing an amber suppressor.

- 5 The term "milk" as used herein is intended to mean any type of milk or milkcomponent which does not contain the precursors for the synthesis of pyrimidine nucleotides including e.g. cow's milk, human milk, buffalo milk, goat's milk, sheep's milk, or whey.
- 10 Evidently, the above-mentioned acidification of milk will result in essentially the same pH decrease in the medium inoculated with the respective strains. However, it is contemplated that with other host strains, the acidification rate may be insignificantly reduced by the presence of the
- 15 vector according to the invention. Accordingly, the expression "at essentially the same acidification rate" includes that in comparative acidification experiments, the  $\Delta$ pH after about 3 hours of cultivation is at the most 1.0 such as at the most 0.5 including at the most 0.2 such as e.g. at the
- 20 most 0.1.

It is another objective of the invention to provide recombinant food-grade vectors that do not inhibit growth rate of lactic bacterial host cells. Thus, as it is also shown in the below examples, the vector of the present invention permits a

25 host cell such as *Lactococcus lactis* FA4-1-1 strain to grow at 30°C in minimal medium at a doubling time which is shorter than that for the strain DN209 transformed with the vector pFG1.1 (DSM 12088). In useful embodiments the doubling time of a host cell transformed with the vector of the invention

30 is at least 5 minutes shorter than that of the strain DN209 transformed with the vector pFG1.1, such as at least 10 minutes shorter e.g. at least 15 minutes shorter or even at least 20 minutes shorter.



In accordance with the invention, the recombinant vector has at least one of the above characteristics (i) to (iii). However, it is preferred that the vector has at least two of such characteristics and most preferably all of these characteristics.

The suppressor gene comprised in the recombinant vector is typically derived from a lactic acid bacterial cell which is subjected to a mutagenization treatment followed by selecting mutants suppressing an amber nonsense mutation e.g. such as it is described by Dickely et al. 1995 and isolating a DNA sequence comprising the mutated suppressor gene. However, the suppressor gene comprised in the recombinant vector can be provided by selecting a spontaneously occurring mutant in accordance with the screening method as described above.

Alternatively, it is possible to construct a tRNA gene coding for the suppressor by conventional DNA synthesis methods or by *in vivo* mutagenesis of isolated genes. Normally, the mutated tRNA-encoding gene is derived from the chromosome of the source strain. Preferably, the suppressor gene encodes a tRNA with an anticodon selectively recognizing amber codons, i.e. an amber suppressor. The nonsense suppressor may be one which results from at least one nucleotide change in a gene coding for a tRNA anticodon resulting in the altered tRNA anticodon CUA. In useful embodiments the suppressor is a *supD*, *supE*, *supF*, *supP*, *supU* or a *supZ* suppressor.

In other specific embodiments, the amber suppressor may be derived by double or triple base substitutions in the anticodon region of the tRNA.

The DNA sequence comprising the tRNA encoding suppressor gene is preferably a small sequence such as a sequence in the range of 0.05 to 10 kb, more preferably in the range of 0.1 to 5.1 kb, such as e.g. 3.2, 1.1 or 0.25 kb. As an example, the DNA sequence coding for such a tRNA may be the following:



1 GGAGCCATGG CAGAGTGGTA ATGCAACGGA CTCTAAATCC GTCGAACCGT  
 51 GTAAAGCGGC GCAGGGGTTC AAATCCCCTT GACTCCTTA

In one interesting embodiment of the present invention, the vector is one wherein the gene coding for a nonsense suppressor is under the control of a regulatable promoter. As used herein, the term "regulatable promoter" is used to describe a promoter sequence possibly including regulatory sequences for the promoter, which promoter is regulatable by one or more factors occurring during the growth of a host cell comprising the recombinant vector. Such factors include the pH and/or the arginine content of the growth medium, the growth temperature, a temperature shift eliciting the expression of heat shock genes, the composition of the growth medium including the ionic strength/NaCl content and the growth phase/growth rate of the lactic acid bacterium. Such a regulatable promoter may be the native promoter or it may be an inserted promoter not naturally related to the suppressor gene either isolated from the lactic acid bacterial species or it may be a heterologous promoter sequence, i.e. a sequence derived from a different lactic acid bacterial species.

A promoter sequence as defined above may comprise further sequences whereby the promoter becomes regulated by a stochastic event. Such a regulation may e.g. be useful in lactic acid bacterial cultures for which it may be advantageous to have a gradually decreasing activity of the suppressor gene under control of the promoter sequence. Such further sequences may e.g. be sequences, the presence of which results in a recombinational excision of the promoter or of genes coding for substances which are positively needed for the promoter function.

In accordance with the present invention, the vector is typically constructed by combining a DNA sequence comprising a suppressor gene which is functional in a lactic acid bacterium and a replicon capable of replicating in a lactic acid



bacterium. In a useful embodiment the replicon is from a *Lactococcus lactis* plasmid. More specifically, the replicon is derived from the *Lactococcus lactis* subsp. *lactis* biovar. *diacetylactis* citrate plasmid pCT1138 or the *Lactococcus*  
5 *lactis* plasmid pIL2608 such as it is described in the following examples.

For a vector construct as described above to be useful as a cloning vector it is provided with at least one restriction site. Preferably, the restriction site(s) is/are unique  
10 sites. In useful embodiments, the vector comprises at least one DNA sequence containing multiple cloning sites.

Examples of vectors, which are encompassed by the present invention, are the multi-copy vectors pFG100 and pFG200 as described in the examples.

- 15 In addition, the present invention encompasses mutants, variants or derivatives having essentially the characteristics of the vectors pFG100 and pFG200. In this context, the terms "mutant", "variant" or "derivative" refers to any modification of the DNA sequence of the above vectors includ-  
20 ing substitution, addition or deletion of nucleotides in the suppressor gene, the replicon, any regulatory DNA sequences or any other sequence of the vector, that substantially does not affect the characteristics of the modified vector, relative to the parent vector.
- 25 Preferably, vectors as described above have a size allowing for the insertion of desirable genes. Accordingly, a suitably sized vector as defined herein has a size which is in the range of 0.5 to 20 kb, although larger vectors may also be used. In preferred embodiments the vector has a size in the  
30 range of 1 to 10 kb, such as in the range of 2 to 5 kb.

The vector according to the invention may further comprise an inserted gene coding for a desired gene product. In this context, interesting desired gene products include genes



coding for enzymes which has an advantageous effect on the quality of a food product, the manufacturing or preservation of which includes the addition of viable lactic acid bacterial cultures as it has been described above. Thus, such genes  
5 inserted into the vector may code for a peptidase, including lysine-aminopeptidase, glutamyl-aminopeptidase, cysteine-aminopeptidase, iminopeptidase, X-prolyl-dipeptidyl aminopeptidase, endopeptidase, dipeptidase or tripeptidase.

In the present context, other interesting gene products  
10 include lipases, proteases, nucleases and enzymes which are involved in the carbohydrate metabolism of the host bacterium. Inserted genes may also be prokaryotic or eucaryotic genes isolated from non-lactic acid bacterial species.

In accordance with the invention, an interesting gene product  
15 includes a gene product conferring bacteriophage resistance to the lactic acid bacterial host cell. In another useful embodiment the vector according to the invention comprises a gene coding for a bacteriophage lysin, which in a specific embodiment is derived from the bacteriophage ØvML3 contained  
20 in the strain DN209/pFG7 deposited with the Deutsche Sammlung von Mikroorganismen und Zellkulturen, Mascheroder Weg, 1b, D - 38124 Braunschweig on 6 April 1998 under the accession No. DSM 12089. In a further specific embodiment the vector according to the invention is a theta-replicating vector.

25 As it mentioned above, it is a further object of the invention to provide food-grade vectors which can be stably maintained in a lactic acid bacterial host cell. Accordingly, there is preferably substantially no loss of the vector when the host strain is grown for at least 20 generations, including  
30 at least 35 generations such as at least 50 generations or even at least 100 generations in a medium wherein a host cell not containing the vector is not capable of growing. Thus, when the host cell comprises a nonsense mutation conferring auxotrophy e.g. with respect to amino acid or  
35 nucleotide precursor compounds, such as purine or pyrimidine



precursors, the vector will be selected (stabilized) in a medium not containing such precursors.

The invention provides in a further aspect a lactic acid  
5 bacterium comprising a vector according to the invention.  
Normally, the bacterium also comprises an amber mutation  
being suppressible by the nonsense amber suppressor. Such a  
gene coding for the nonsense mutation may be located on a  
10 replicon different from the one containing the gene coding  
for a nonsense suppressor, e.g. on the chromosome, on a  
plasmid or it may be incorporated in the cell as a prophage.

In certain preferred embodiments, the lactic acid bacterium  
of the present invention comprises a suppressor which is  
capable of suppressing a nonsense mutation which, in the  
15 absence of the nonsense suppressor, confers auxotrophy. Such  
a nonsense mutation may e.g. be in a gene involved in the  
synthesis of pyrimidine nucleotides from their precursors in  
which case the lactic acid bacterium is a nonsense *pyr* mutant  
such as a *pyrF*<sup>-</sup> mutant.

20 The lactic acid bacterium of the invention can be any lactic  
acid bacterium selected from the group consisting of a *Lacto-*  
*coccus* sp., *Streptococcus* sp., *Lactobacillus* sp., *Leuconostoc*  
sp., *Pediococcus* sp. and *Bifidobacterium* sp. One preferred  
species is *Lactococcus lactis* including *Lactococcus lactis*  
25 subsp. *lactis*. Examples of strains belonging to the latter  
species include strain FA4-1-1 containing pFG100, deposited  
under the accession No. DSM 12091 and *Lactococcus lactis*  
subsp. *lactis* strain CHCC4146 containing pFG200, deposited  
under the accession No. DSM 12108.

30 In a still further aspect, the invention relates to an iso-  
lated pure culture of a lactic acid bacterium as defined  
above, the expression "pure culture" indicating that the  
culture contains a biomass of one single isolate of a lactic  
acid bacterial species, i.e. a clone originating in principle  
35 from one cell. Such a pure culture may be provided as a



liquid cell suspension or as frozen or freeze-dried preparation. Preferably the pure culture is in a concentrate of cells obtained by separation e.g. by centrifugation or filtration using conventional techniques.

- 5 In yet a further aspect, the present invention relates to a composition comprising an isolated pure culture of a lactic acid bacterium as defined above, and a microbiologically acceptable carrier. It may be preferred that such a composition contains at least  $10^5$  colony forming units (CFUs) of the  
10 bacterium such as at least  $10^7$  or at least  $10^9$  CFUs per g. Suitable carriers substances include nutrients such as an assimilable carbohydrate or a nitrogen source, which can be utilized readily by the lactic acid bacterium. Typically, such a composition is provided in the form of a frozen or  
15 freeze-dried composition. In the latter case, the composition may contain cryoprotective compounds.

- The composition may, in accordance with the invention, comprise two or more different species of lactic acid bacteria or two or more strains of the same species. It is common in  
20 the production of food products, where lactic acid bacterial starter cultures are used, to apply mixed cultures, i.e. cultures comprising a multiplicity of strains. As an example hereof it can be mentioned that a mixed culture of  
*Lactobacillus bulgaricus* and *Streptococcus thermophilus* is  
25 typically used in the production of yoghurt. In other dairy products a mixed culture of *Bifidobacterium bifidum* and *Lactobacillus acidophilus* are used.

- In further aspects, the invention relates to the use of the above composition as a starter culture in the preparation of  
30 a food product such as e.g. a dairy product, a vegetable product, a meat product, a bakery product or a wine product, and its use in the production of an animal feed such as silage, from e.g. grass, cereal, peas, alfalfa or sugar-beet leaf, where starter cultures are inoculated in the feed crop  
35 to be ensiled in order to obtain a preservation hereof, or in



protein rich animal waste products such as slaughtering offal and fish offal, also with the aims of preserving this offal for animal feeding purposes. Yet another significant application of lactic acid bacterial cultures according to the  
5 present invention is the use of such cultures as so-called probiotics. By the term "probiotic" is in the present context understood a microbial culture which, when ingested in the form of viable cells by humans or animals, confers an improved health condition, e.g. by suppressing harmful micro-  
10 organisms in the gastrointestinal tract, by enhancing the immune system or by contributing to the digestion of nutrients.

In another specific embodiment, the above composition is used as a starter culture in the preparation of a starter  
15 distillate used for e.g. flavouring of butter, margarine, spreads, cereal products or pop-corn, or for a product for cheese flavouring.

In accordance with the present invention there is also provided a method of stably maintaining a vector of the  
20 present invention in lactic acid bacterial host cells growing in a particular environment, comprising providing said host cells as nonsense mutant cells having lost the capability of growing in said environment, and transformed with a vector according to the invention containing a nonsense suppressor  
25 gene encoding a gene product restoring the capability of the nonsense mutant cells to grow in said environment whereby, if the vector is lost from the lactic acid bacterial cells, the cells will not grow.

In suitable embodiments of the invention, the lactic acid  
30 bacterial host cells harbouring the vector to be stably maintained have a nonsense mutation in one or more genes conferring auxotrophy to the cells whereby the cells have lost their capability to grow in the particular environment due to a lack herein of an essential nutrient substance which  
35 cannot be synthesized by the nonsense mutant cells.



As one example, the nonsense mutation may be one which causes the host cells to lose the capability to grow in a medium which does not contain pyrimidines.

Accordingly, the suppressor gene of the vector functions as a selective marker for the lactic acid bacterial host cells. In the present context, the term "a selective marker" is used to designate a gene coding for a product which renders lactic acid bacterial cells unable to grow if the vector to be maintained is lost from the cells.

It is contemplated that auxotrophic nonsense mutants may be isolated, which allow a vector to be stably maintained in a lactic acid bacterium growing in specific environments including milk, a vegetable material, a meat product, a must, a fruit juice, a wine, a dough, a batter, the gastrointestinal tract, feed crops or offal to be ensiled by a lactic acid bacterium.

The invention is further illustrated in the following non-limiting examples and the drawings wherein

Fig. 1 illustrates the construction of vector pFG100.

Ligation of a 2.8 kbp *EcoRI*-*Bam*HI DNA fragment carrying the replicon of vector pIL2608 and a 298 bp PCR fragment containing *supD* suppressor allele;

Fig. 2 shows the growth rate of strain FA4-1-1 harbouring pFG100 compared to the growth rate of strain DN209 harbouring pFG1.1;

Fig. 3 illustrates the construction of vector pMPJ100. Ligation of a 2.8 kbp *EcoRI* DNA fragment carrying the replicon of plasmid pIL2608 and a 298 bp PCR fragment containing *supD* suppressor allele. Filled-in arrows indicate the deletion of the non food-grade part by *Bam*HI digestion of pMPJ100 to generate the food-grade vector pFG100. Only unique cloning sites in pMPJ100 are shown (except *Bam*HI);



Fig. 4 illustrates the construction of vector pFG200. Ligation of an *EcoRI* digestion of plasmid pKR41 carrying a replicon and an *EcoRI* digestion of pAK93 carrying the amber suppressor resulting in the plasmid pMPJ103. *HindIII*-digestion of pMPJ103, self-ligation and electroporation of strain FA4-1-1, resulting in vector pFG200;

Fig. 5 shows the DNA sequence of the *pyrF* gene of FH CY-1;

Fig. 6 illustrates the construction of a *pyrF*<sub>amber</sub> mutation;

Fig. 7 illustrates the introduction of the *pyrF*<sub>amber</sub> mutation into the host strains chromosome; and

Fig. 8 shows the pH development during 16 hours in whole milk inoculated with strain FH CY-1 or strain CHCC4171 (FH CY-1 *pyrF*<sub>amber</sub> containing pFG100).

#### EXAMPLES

#### 15 Materials and Methods for the construction of the food-grade vectors pFG100, pFG101 and pFG200

##### (1) Bacterial strains and plasmids

The following *Lactococcus lactis* strains were used in the examples: strain MG1363 is a plasmid-free derivative of *Lactococcus lactis* strain NCDO 712 (Gasson, 1983). Strain FA4-1-1 deposited on 6 April 1998 under the accession No. DSM 12086 with the Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, Mascheroder Weg 1b, D-38124 Braunschweig, Germany having a nonsense mutation that is a pyrimidine auxotroph (*pyrF*) of strain MG1363, suppressible by an amber suppressor. Strain CHCC4146 deposited on 17 April 1998 under the accession No. DSM 12109 with the Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, Mascheroder Weg 1b, D-38124 Braunschweig, Germany is a pyrimidine auxotroph (*pyrF*)



of strain FH CY-1 having a nonsense mutation that is suppressible by an amber suppressor.

The following plasmids were used as sources for replicons: *Lactococcus lactis* plasmid pIL2608 (INRA, France), and *Lactococcus lactis* subsp. *lactis* biovar. *diacetylactis* citrate plasmid pCT1138.

#### (ii) Growth media and conditions

When strain MG1363 was grown in liquid medium, M17 with 0.5% glucose (GM17) was used. Strain FA4-1-1 or other *pyrF*- derivatives were cultivated in GM17 medium or DN minimal medium (Dickely et. al. 1995) with 40  $\mu$ g/ml uracil and/or 40  $\mu$ g/ml thymidine added. Solid medium (agar plates) was made by the addition of 1.5% agar to the liquid medium. Selection and maintenance of vectors carrying the *supD* allele in *pyrF* strains was performed in minimal medium without pyrimidine sources. Selection of plasmid pMPJ100 was also carried out in media containing 10g tetracycline. The growth temperature was 30°C. Exponential growth on minimal medium was measured by monitoring the increase in OD at 600 nm.

#### 20 (iii) Preparation of competent cells

Competent cells of strain MG1363 and derivatives were prepared by growing the cells in rich medium containing 1% glycine and for FH CY-1 derivatives 1.5% lysin (Holo and Nes, 1989).  
25 Pyrimidine requiring strains were grown in medium containing 40  $\mu$ g/ml uracil and/or 40  $\mu$ g/ml thymidine to reduce the frequency of revertants. Cells were harvested at an OD<sub>600</sub> of 0.6-0.8, resuspended in 0.5M sucrose/10% glycerol and then frozen at -80°C.



(iv) Electroporation of glycine-grown competent cells

The conditions for electroporation were in all experiments: 25  $\mu$ F, 200 W, 2.0 kV. Using these conditions with desalted DNA, the typical time constant was 4.8 (Holo and Nes, 1989).

5 (v) Plasmid purification

Purification of plasmids from lactococcal strains was carried out as described by Pedersen et al. 1994. Larger preparations of plasmid DNA were prepared using a plasmid purification kit as described by the supplier (QIAGEN®, Stratagene®, Genomed®) 10 by including an initial step of lysozyme treatment. Plasmid DNA preparations were kept at 4°C in 10 mM Tris (pH 7.5).

(vi) PCR-reactions

PCR-amplification of the *supD* gene was performed using 50 ng of pAK89 as template, 10-50 pmol of each primer, 0.25 mM of 15 dNTP, 0.5 units of Taq enzyme in diluted (1x) buffer, which is supplied with the enzyme. The total volume was 50  $\mu$ l. The reaction conditions were: 94°C for 4 min, 35 cycles of 94°C, 1 min; 50°C, 1 min, 72°C; finally 72°C for 7 min.

(vii) Agarose gel electrophoresis

20 Agarose gel electrophoresis was used for verification of purified DNA, digested DNA, ligated DNA or for further purification of separated DNA fragments. To separate DNA fragments above 500 bp, DNA was loaded and electrophoresed through an agarose gel made with 1% agarose in a Tris-Borate, 25 EDTA buffer. To test and separate DNA fragments less than 500 bp in size, a gel with a higher agarose content was used (1.5-2%). The electrophoresis was performed by applying 100V for 45-60 minutes using a Biorad Power supply Model 200, 2.0.



## EXAMPLE 1

The construction of the food-grade vector pFG1001.1 Introduction

In order to use genetically manipulated microorganisms in food products, vectors that are derived totally from the organism to be manipulated are desirable. A useful vector contains a replication region, a selectable marker and a multiple cloning site allowing insertion of desirable genes. In addition, it should be small enough to allow insertion of desired DNA without difficulty.

A multi-copy food-grade cloning vector, pFG100 replicating in lactic acid bacteria was constructed which is based totally on DNA sequences from *Lactococcus*. pFG100 contains the replication region of the *Lactococcus lactis* plasmid pIL2608, an amber suppressor encoding gene, *supD*, and a multiple cloning site. The plasmid is present in >5 copies per cell and exhibits a stable phenotype in various Lactococcal strains.

1.2 Construction of pFG100 by combining the replication region with the suppressor gene

Vector pFG100 was constructed by ligation of a 2.8 kbp *EcoRI*-*BamHI* DNA fragment carrying the replicon of the plasmid pIL2608 to a 298 bp PCR fragment containing the *supD* suppressor allele. This PCR fragment was generated with plasmid pAK89 (Dickely et al. 1995) as template by using primers amber-3 (GAATTCATATTTGATTAATGAGAATATGGAACC) and amber-4 (CGGGATCCTTTCAGGAAGGTAATTAAC) complementary to the promoter region and downstream region of *supD* (Fig. 1). The primers were carrying *EcoRI* and *BamHI* linkers respectively, which after digestion gave ends compatible for ligation to the replicon fragment of pIL2608.



### 1.3 Selection of pFG100

As the primary bacterial host strain for the ligated DNA, strain MG1363 was chosen as this strain can be made more competent than the *pyrF* strain FA4-1-1.

- 5 Since strain MG1363 does not carry a stop-codon in the *pyrF* gene, this strain cannot be used for direct selection of pFG100. In order to select for pFG100, strain MG1363 was co-transformed with pFDi3 (Dickely et. al. 1995), which carries an amber stop-codon in the gene coding for erythromycin  
10 resistance. Using this approach a total of 18 colonies were obtained on GM17 agar plates containing 1 µg/ml erythromycin. No colonies appeared on the control plate (MG1363/pIL2608+pFDi3). Eight of the colonies were streaked to single colonies for purification and after plasmid preparation,  
15 one clone harbouring pFDi3 and pFG100 was selected. After agarose gel electrophoresis, vector pFG100 was cut out from the gel.

### 1.4 Transformation of the bacterial strain FA4-1-1

- The isolated pFG100 vector was introduced into FA4-1-1 by  
20 electroporation of glycine-grown competent cells to transform FA4-1-1 to pyrimidine prototrophy. The strain FA4-1-1 containing the vector pFG100 was deposited on 6 April 1998 under the accession No. DSM 12091 with the Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, Mascheroder Weg 1b, D-  
25 38124 Braunschweig, Germany.

- The electroporation efficiency with pFG100 into FA4-1-1 is highly variable. To obtain good competent cells of FA4-1-1, it is recommended that the strain is grown exponentially in the presence of a pyrimidine source as described above. The  
30 OD at 600 nm should not exceed 0.7. Using these conditions, good competent cells were obtained regularly. The typical electroporation efficiency with pFG100 DNA has been calculated to  $1.5 \times 10^5$  colonies per µg DNA. For direct electropora-



tion of small amounts of ligated DNA, FA4-1-1 was found to be unsuitable as host.

#### 1.5 Growth and stability of bacterial strains harbouring pFG100

- 5 pFG100 can be transformed into the bacterial host strain FA4-1-1 with relatively good efficiency and then isolated with reproducible result. Plasmid isolations from FA4-1-1 tend to yield chromosomal DNA to a higher level than usual.

- The growth rate of FA4-1-1 harbouring pFG100 has been  
 10 measured and compared to the growth rate of DN209/pFG1.1 deposited on 6 April 1998 under the accession No. DSM 12088 with the Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, Mascheroder Weg 1b, D-38124 Braunschweig, Germany (Table 1 and Fig. 2). Vector pFG1.1 is a pFG1 derivative  
 15 (Dickely et. al. 1995) with a mutation in the *supB* promoter, which reduces *supB* expression and allows the host strain to grow faster.

20 Table 1. Growth rate of strain FA4-1-1 harbouring pFG100 compared to the growth rate of strain DN209 harbouring pFG1.1. on minimal medium.

Time	pFG1.1	pFG100
12:01	0.20	0.21
12:50	0.27	0.30
13:48	0.37	0.57
15:05	0.61	1.04
16:00	0.84	1.41

FA4-1-1/pFG100 was found to grow with a doubling rate of 86 minutes which is 19 min faster than DN209/pFG1.1 (105 minutes) (Fig. 2).



### 1.6 Stability of pFG100 in industrial production strains

To test the stability of pFG100 in production strains, the vector was transformed into the *pyrF*-derivative of strain FH CY-1, strain CHCC4146 to produce strain CHCC4171 which was deposited on 6 April 1998 under the accession No. DSM 12090 with the Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, Mascheroder Weg 1b, D-38124 Braunschweig, Germany. The vector was found to be maintained and co-exist with the plasmids of that strain. Importantly, it was also found that growth and lactic acid production was virtually unaffected by the presence of the vector (see Example 4).

### 1.7 Plasmid copy number of pFG100

The copy number of pFG100 was determined by visual comparison by agarose gel electrophoresis with the vector pFG1 which was deposited on 6 May 1994 under the accession No. DSM 9190 with the Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, Mascheroder Weg 1b, D-38124 Braunschweig, Germany. These data indicate that pFG100 is present in 5-8 copies per cell corresponding to the copy number of vector pFG1.

## 20 EXAMPLE 2

The construction of the non-food grade vector pMJP100 as an intermediate to obtain the food-grade vector pFG101

### 2.1 Introduction

The primary host strain FA4-1-1 exhibits a quite high reversion rate and is difficult to make competent enough for electroporation with ligation mixtures i.e. initial screenings of clones. To circumvent this problem, the pMPJ100 vector was constructed. Like pFG100, this vector is also based on the pIL2608 replicon but in addition to the *supD* gene, the *tet* gene is present on the plasmid. This means that



the cloning of relevant genes can be screened in MG1363 by selecting for tetracycline resistance. Conversion to food-grade status can then be carried out by a *Bam*HI digestion, ligation and transformation into the final *pyrF* amber host.

5    2.2 Construction of plasmid pMPJ100 by combining the replicon region with the suppressor gene

Plasmid pMPJ100 was constructed by digestion of plasmid pIL2608 with *Eco*RI and the DNA with a PCR fragment carrying the *supD* allele (Fig. 3). This PCR fragment was generated  
10 with the plasmid pAK89 (Dickely et. al. 1995) as described in Example 1, but instead of using primer amber-4, primer amber-6 (GGGAATTCAGGAAGGTAATTAAC) was used to obtain *Eco*RI compatible sites in both ends of the fragment.

15    2.3 Transformation of the bacterial strain MG1363 with pMJ100

The ligation mixture was introduced into MG1363 by electroporation. Electroporation with ¼ of the ligation mixture into MG1363 resulted in more than 300 colonies on GM17 agar plates containing 10 tetracycline. Ten colonies from this plate were  
20 further purified and used for isolation of plasmid DNA. Two of the 10 colonies were found to contain the *supD* allele cloned in the same orientation (Fig. 3).

The electroporation efficiency with pMPJ100 DNA is typically the same as with pFG100, as described in Example 1. The  
25 electroporation efficiency has been calculated to  $1-5 \times 10^5$  colonies per µg DNA.

2.4 Deletion of the nonfood-grade components of pMJ100 to obtain the food-grade vector pFG101

Food-grade vector pFG101 can be derived directly from pMPJ100  
30 by *Bam*HI digestion, ligation and transformation into a *pyrF*-amber host strain (Fig. 3).



## EXAMPLE 3

Construction of the food-grade expression vector pFG200

The complete minimal replicon of the *L. lactis subsp. lactis* biovar *diacetylactis* citrate plasmid pCT1138 has been cloned  
 5 as a 1.7 kb polymerase chain reaction (PCR) fragment flanked by *EcoRI* sites (Pedersen et al., 1994). This fragment contains the origin of replication, the *repB* gene and ~300bp of flanking DNA and was cloned in pIC19H (ampicillin resistant, Amp<sup>R</sup>) to produce pKR41.

10 PCR was performed on pAK89 using primers amber-2 (CGAATTCAACATTTTGTATAAATATGCG) and amber-3 (GAATTCATATTTGATTAATGAGAATATGGAACC) (Fig. 4) to produce a PCR fragment containing the tRNA promoter, the suppressor gene and downstream sequences flanked by the *EcoRI* sites provided  
 15 by the primers. This 360 bp *EcoRI* fragment was cloned in pIC19H to give pAK93.

The *supD* allele is a suitable selectable marker when combined with the pyrimidine auxotroph FA4-1-1. This strain only grows in pyrimidine-free medium in the presence of the amber sup-  
 20 pressor. DNA of pAK93 and pKR41 was digested with *EcoRI*, mixed, ligated and electroporated into FA4-1-1 followed by selecting prototrophs. This selection ensures that colonies contain plasmids with the suppressor gene and the citrate plasmid replicon. Some plasmids will also contain pIC19H.  
 25 These were obtained by pooling several hundred colonies, extracting plasmid DNA and transforming *E. coli* selecting Amp<sup>R</sup>. One plasmid with the desired structure was designated pMPJ103.

All pIC19H except the polylinker was deleted by digesting  
 30 pMPJ103 with *HindIII*, self ligating, and electroporating FA4-1-1 selecting prototrophs. The resulting colonies contained a single plasmid of 2.2 kb containing the citrate plasmid



replicon, the amber suppressor and the polylinker. One was saved and the plasmid designated pFG200. The vector pFG200 was transformed into the *pyrF*-derivative of strain FH CY-1, strain CHCC4146 to produce strain CHCC4223 which was

5 deposited on 16 April 1998 under the accession No. DSM 12108 with the Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, Mascheroder Weg 1b, D-38124 Braunschweig, Germany. The structure of pFG200 is illustrated in Fig. 4. The resulting polylinker is identical to that found in pIC19R (Marsh et

10 al., 1984) and contains the following unique sites: *Sma*I, *Bam*HI, *Sal*I, *Pst*I, *Hind*III, *Nru*I, *Xho*I, *Sac*I, *Bgl*II, *Xba*I and *Eco*RV.

#### EXAMPLE 4

Construction of *pyrF*<sub>amber</sub> mutants of the industrial strain

15 *Lactococcus lactis* FH CY-1

##### 4.1 Introduction

In order to use the previously described food-grade expression vectors based on a *supD* suppressor capable of suppressing amber mutations, appropriate mutations in a number of industrial *Lactococcus* strains are needed. Rather than use chemical mutagenesis with its inherent problems, single precise

20 alteration in the chromosome of the strains to be used as host for pFG100 or pFG200 were carried out. The *pyrF* gene was chosen because it exists in single copy in the *Lactococcus*

25 chromosome, the DNA sequence is known from MG1363, mutants should have an absolute requirement for pyrimidines for growth, and milk does not contain enough pyrimidines to allow growth of the mutants. Thus, milk would be a selective medium for this plasmid.

30 The DNA sequence of the *pyrF* gene of FH CY-1 was determined, the *pyrF* genes was cloned and amber mutations introduced by polymerase chain reaction. Finally, gene replacement was used



to introduce the constructed amber mutation into the chromosome of FH CY-1.

#### 4.2 Materials and methods

##### 5 (i) Growth media and strains

*Lactococcus lactis* was grown in M17 or DN minimal medium (Dickely et al., 1995). *Escherichia coli* was grown in LB-media, supplemented with ampicillin to 50 mg/ml when required. For growth of pyr<sup>-</sup> strains, uracil was added to 20 mg/ml. Competent cells of FH CY-1 were made by growth in the presence of 1.5% glycine (Holo and Nes, 1989).

Strain FH CY-1, which was deposited on 6 April 1998 under the accession No. DSM 12087 with the Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, Mascheroder Weg 1b, D-38124 Braunschweig, Germany, is the industrial strain of *Lactococcus lactis* also known as CHCC377 and is the major component of the R604 culture. *Escherichia coli* strain DH5 $\alpha$  was used for cloning in pIC19H.

##### (ii) DNA preparation and manipulations

Plasmid preparations from *Escherichia coli* was prepared by using a plasmid purification kit as described by the supplier (QIAGEN®, Stratagene®, Genomed®) by including an initial step of lysozyme treatment. Plasmid DNA was isolated from *Lactococcus lactis* by using the procedure of Pedersen et al. 1994 with the modification that 50ml of 5M NaCl was added before the phenol extraction. Chromosomal DNA was purified from *Lactococcus lactis* by using the procedure of Johansen and Kibenich, 1992.

Digestion with restriction enzymes, ligations and polymerase chain reactions were made by following the procedure of the manufacturers of the various enzymes and kits. DNA sequencing was by cycle sequencing as recommended by Perkin-Elmer. The



resulting products were purified on BioRad Micro-Bio-Spin-Chromatography columns before running on the ABI310 DNA sequencer.

Primers were as follows:

5	pyrF1	GCAGATCTAAGCTTGATTCAAGAAGTAAAAGAAGGC
	pyrF2	ATAGATCTACTCGATGCCAAGAATGGACCGC
	pyrF3	AAAGGCCTGTNATNGCNCNTNGAYTTYCC
	pyrF4	TGGACGAATTCNNGNGT
	pyrF5	CATAGTAAACGACTTGGGG
10	pyrF6	TACGCACAAAAAACCGCT
	pyrF7	GGTCGCCTTTACTTGCACC
	pyrF8	GATTATATTGTTGTCGGCCG
	pyrD-degn	GCTCTAGAGCMWATYGWWATDGGN
	llagidB2	GGTNGARTGGAAYGARAARATHAAY
15	Fam5	CCTCAACCTAGGAGAAAAATTATGC
	Fam6	TCTCCTAGGTTGAGGTTAATTGTG
	pyrD/BglII	ATAGATCTGCTTAGAAAACTTG
	pyrF11/BglII	ATAGATCTGCATGTAAGCAAAAACC

(iii) Plasmid stability in milk

- 20 A fresh overnight culture of CHCC4171 (DSM 12090) in minimal medium was subcultured 1:100 (100  $\mu$ L into 10 ml) in reconstituted skim milk (RSM) and incubated overnight. The resulting culture was plated on M17 plates and subcultured 1:100 in RSM. This procedure was repeated for five consecutive days.
- 25 Each outgrowth was taken to be 7 generations ( $2^7=128$ ). After each outgrowth, 100 single colonies were picked and patched onto minimal and minimal + uracil plates. A strain which has lost the pFG100 plasmid will be unable to grow on minimal plates but will grow on minimal + uracil plates. A strain
- 30 retaining the plasmid will grow on both plates. To confirm this, plasmids were isolated from 10 colonies after 35 generations. All had the expected plasmid profile.



(iv) Acidification studies in whole milk

Single colonies of strain FH CY-1 (DSM 12087), and CHCC4171 (FH CY-1 *pyrF<sub>amber</sub>*/pFG100), DSM 12090) were inoculated in M-17 or DM-9,5-UA media. The cultures were incubated for 24  
 5 hours at 30°C. Subsequently, the cultures (1%) were inoculated in whole milk and incubated in a warm water-bath (Profilur) equipped with a pH-electrode (Hammilton). The pH development was registered continuously for 16 hours. In addition, comparative acidification studies with strain FH  
 10 CY-1 and CHCC4223 (FH CY-1 *pyrF<sub>amber</sub>*/pFG200), DSM 12108) were performed in accordance with the method as described above.

4.3 Sequencing of the *pyrF* gene of strain FH CY-1

The DNA sequence of the *pyrF* gene of MG1363 is known (Andersen et al., 1994). Primers based on this sequence  
 15 (*pyrF*1 and *pyrF*2, Table 2) were tested but could not be used to clone or sequence the *pyrF* gene of FH CY-1. Based on an amino acid sequence comparison of the *pyrF* gene product of a number of microorganisms, two degenerate primers (*pyrF*3 and *pyrF*4) were made and used to amplify a 550 bp internal *pyrF*  
 20 fragment. This fragment was sequenced with the same primers. Based on this sequence, new primers were ordered (*pyrF*5 and *pyrF*6) and used for inverse PCR with *Sau*3AI digested DNA. This gave additional sequence data. The sequence of the amino terminal end of *pyrF* was completed using a degenerate primer  
 25 designed from the sequence of *pyrD* (*pyrD*-dgen) which is immediately upstream of *pyrF* and two additional primers (*pyrF*7 and *pyrF*8). The carboxy terminal end of *pyrF* was sequenced using a degenerate primer (*l*lagidB2) designed from the sequence of *gidB*, which is immediately downstream of  
 30 *pyrF*, and *pyrF*6. The DNA sequence of the *pyrF* gene of FH CY-1 is presented in Fig. 5. This gene is 86% identical to the *pyrF* gene of MG1363.

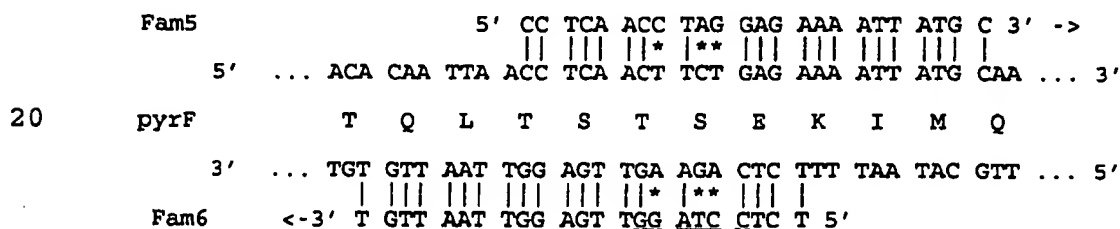


#### 4.4 Cloning of the *pyrF* gene of strain FH CY-1

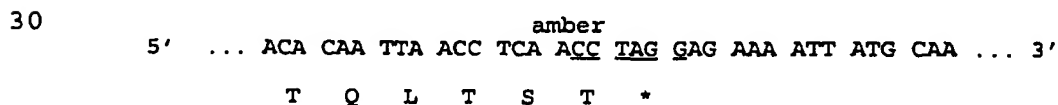
Primers for PCR amplification were designed from the DNA sequences determined above (*pyrD*/BglII and *pyrF11*/BglII). They contain BglII restriction sites and allow amplification of a ca. 1.1 kb DNA fragment containing the entire *pyrF* gene. This fragment was cloned into pIC19H digested with BglII. The *pyrF* gene of strain FH CY-1 is contained in a plasmid designated pAK142.

#### 4.5 Introduction of an amber mutation into the cloned *pyrF* genes

The strategy used involves searching the DNA sequence for a serine codon (TCT, TCC, TCA, TCG, AGT or AGC) that can be changed to amber (TAG) and which is flanked by sequences that allow the introduction of a restriction enzyme recognition site without affecting the amino acids encoded by the flanking sequences. This is illustrated below:



The PCR primers are called Fam5 and Fam6 and are indicated above and below the sequence of this region of *pyrF*. The mismatched base pairs are indicated by \*. The outside primers are *pyrF11*/BglII and *pyrD*/BglII to facilitate cloning of the resulting PCR products. Following PCR and cloning as described in Figure 6, the DNA sequence will be:





where the amber codon is indicated by \* and the introduced AvrII restriction site is underlined. Suppression of this amber mutation by *supB* will introduce a serine and the amino acid sequence of the resulting protein will be identical to  
 5 that of the parent strain.

The *pyrF*<sub>amber</sub> DNA fragment was cloned in pIC19H to make plasmid pAK148 and the DNA sequence determined. No undesired changes were detected.

#### 4.6 Introduction of the amber mutation into the chromosome

- 10 The *pyrF*<sub>amber</sub> DNA fragment was subcloned into pG<sup>+</sup>Host9 to produce plasmid pAK149. The pG<sup>+</sup>Host vectors are temperature sensitive for replication and can be used to integrate DNA into the *Lactococcus* chromosome. These vectors replicate at 30°C but not at temperatures above 36°C. The strain FH CY-  
 15 1/pAK149 was constructed by electroporation and is resistant to erythromycin by virtue of the erythromycin-resistance gene present in pG<sup>+</sup>Host9.

- When FH CY-1/pAK149 is incubated at 38.0°C and plated on M17 Ery plates, surviving colonies will be strains in which  
 20 pAK149 has integrated into the chromosome by homologous recombination between the *pyrF*<sub>amber</sub> fragment on pAK149 and the *pyrF* gene on the chromosome. The resulting strains have two copies of *pyrF*, one normal and one mutant. One such strain was purified and saved as FH CY-1/pAK149 Nr 1.
- 25 Bacteria cannot survive if they have two active replicons in their chromosome, so incubation of a strain like FH CY-1/pAK149 Nr 1 at 30°C will select for strains in which the integrated pG<sup>+</sup>Host derivative has been removed. This can most easily occur by a second homologous recombination event.
- 30 Depending on where this event occurs, the chromosome will either contain the normal *pyrF* gene or the *pyrF*<sub>amber</sub> gene. Strains in which the desired recombination event has occurred are found by screening survivors isolated on M17 plates at



30°C for their pyrimidine requirement. Strains that do not require pyrimidines for growth have the normal *pyrF* gene while strains that require pyrimidines have the *pyrF<sub>amber</sub>* gene. This process of integration and excision of pAK149 is  
 5 illustrated in Figure 7. The overall result is that the *pyrF<sub>amber</sub>* gene originally on the plasmid and indicated by the dark line replaces the *pyrF* gene originally on the chromosome.

Pyr<sup>-</sup> survivors were tested for the presence of the amber  
 10 mutation by amplifying the *pyrF* gene via PCR and confirming that the *AvrII* restriction site was still present. The DNA sequence of the *pyrF* gene was also determined following PCR amplification. One strain with exactly the desired DNA sequence of the *pyrF<sub>amber</sub>* gene was saved as CHCC4146 and  
 15 deposited on 17 April 1998 under the accession No. DSM 12109 with the Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, Mascheroder Weg 1b, D-38124 Braunschweig, Germany. Thus, the strain CHCC4171 (DSM 12090) may be cured for the vector pFG100 to obtain strain CHCC4146 as described  
 20 in Dickely et al. 1995 and WO 95/10621.

#### 4.7 Introduction of pFG100 into CHCC4146 and characterization of CHCC4171

Competent cells were made and electroporation with pFG100 were done. Ten colonies growing on minimal medium were  
 25 purified and plasmid analysis showed that five of the colonies contained pFG100. The other five were spontaneous *pyr<sup>+</sup>* revertants. One strain was saved and designated CHCC4171 (DSM 12090).

Plasmid stability was tested and 100 of 100 colonies tested  
 30 at each of 7, 14, 21, 28 and 35 generations in milk were found to contain pFG100. Thus, this plasmid is very stable in the FH CY-1 background. This is a significant improvement over the pFG1 system (WO 95/10621) which had over 90% plasmid-free cells after 40 generations in milk.



The acidification of milk by FH CY-1 and CHCC4171 was assessed as described above. The two strains were virtually indistinguishable and showed the high rate of acidification characteristic for FH CY-1 (Figure 8). Furthermore, the  
5 acidification rate of strain CHCC4223 was as high as that of strain CHCC4171 and virtually indistinguishable from strain FH CY-1. This too was a significant improvement over the pFG1 system where the acidification rate for various FH CY-1 derivatives was considerably reduced.



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Genetic analysis of the minimal replicon of the *Lactococcus*  
*lactis* subsp. *lactis* biovar. *diacetylactis* citrate plasmid.  
Mol Gen Genet 244: 347-382.



## CLAIMS

1. A recombinant vector consisting essentially of lactic acid bacterial DNA, the vector comprising a gene coding for a tRNA comprising an amber suppressor and a replicon making the  
5 vector capable of replicating in a lactic acid bacterium, the vector having at least one of the following characteristics:
  - (i) when it is present in *Lactococcus lactis* strain FA4-1-1 (DSM 12086) having an amber mutation in the *pyrF* gene that is suppressible by the suppressor, it permits said strain to  
10 grow at 30°C at a doubling time of at the most 100 minutes in a minimal medium not containing pyrimidine sources;
  - (ii) when it is present in a strain of *Lactococcus lactis* FH CY-1 that has an amber mutation in the *pyrF* gene (strain CHCC 4146, DSM 12109), the amber mutation being suppressible by  
15 the suppressor, it permits the strain to acidify milk under identical conditions at essentially the same rate of that of the parent strain (FH CY-1, DSM 12087);
  - (iii) it permits the *Lactococcus lactis* FA4-1-1 strain to grow at 30°C in a minimal medium not containing pyrimidine  
20 sources at a doubling time which is less than that for the *Lactococcus lactis* strain DN209 transformed with the vector pFG1.1 (DSM 12088), the pFG1.1 vector comprising a gene coding for a suppressor that is capable of suppressing the amber mutation in the DN209 strain, the transformed DN209  
25 strain growing under conditions identical to those for the FA4-1-1 strain.
2. A vector according to claim 1 which has at least two of the characteristics (i) to (iii).
3. A vector according to claim 1 which has the characteris-  
30 tics (i) to (iii).



4. A vector according to claim 1 wherein the gene coding for the nonsense suppressor is derived from the chromosome of a lactic acid bacterium.
5. A vector according to claim 4 wherein the gene coding for a nonsense suppressor is under the control of a regulatable promoter.
6. A vector according to claim 5 wherein the regulatable promoter is a promoter not naturally related to the gene.
7. A vector according to claim 1 wherein the amber suppressor results from at least one change of nucleotide in an anticodon.
8. A vector according to claim 7 wherein the suppressor has two or three changes of nucleotide.
9. A vector according to claim 7 or 8 wherein the suppressor comprises a CUA anticodon.
10. A vector according to claim 9 wherein the suppressor is a suppressor selected from the group consisting of a *supD*, *supE*, *supF*, *supP*, *supU* and a *supZ* suppressor.
11. A vector according to claim 1 wherein the replicon is derived from a *Lactococcus lactis* plasmid.
12. A vector according to claim 1 that comprises at least one unique restriction site.
13. A vector according to claim 1 that comprises a multiple cloning site.
14. A vector according to claim 1 which is a theta-replicating plasmid.



15. A vector according to claim 1 which is stably maintained for at least 35 generations in a lactic acid bacterium cultivated in a medium not containing pyrimidine sources.
16. A vector according to any of claims 1-15 which is  
5 selected from the group consisting of pFG100 deposited under the accession No. DSM 12091, a mutant, variant or derivate of pFG100, pFG200 deposited under the accession No. DSM 12108 and a mutant, variant or derivate of pFG200, said mutants, variants or derivatives essentially having the characteristics  
10 of the respective vector from which they are derived.
17. A vector according to claim 1 which comprises a gene coding for a desired gene product.
18. A vector according to claim 17 wherein the gene product is a peptidase selected from the group consisting of lysine-  
15 aminopeptidase, glutamyl-aminopeptidase, cysteine-aminopeptidase, iminopeptidase, X-prolyl-dipeptidyl aminopeptidase, endopeptidase, dipeptidase and tripeptidase.
19. A vector according to claim 17 wherein the gene product confers bacteriophage resistance to a lactic acid bacterial  
20 host cell.
20. A vector according to claim 17 wherein the gene product is a bacteriophage lysin.
21. A vector according to claim 20 wherein the gene coding for the bacteriophage lysin is derived from the bacteriophage  
25 ØvML3 as contained in DN209/pFG7 deposited under the accession No. DSM 12089.
22. A lactic acid bacterium comprising a vector according to any of claims 1-21.



23. A lactic acid bacterium according to claim 22 that comprises an amber mutation being suppressible by the nonsense amber suppressor.
24. A lactic acid bacterium according to claim 23 wherein the  
5 amber mutation is located on a replicon different from the one containing the gene coding for the nonsense suppressor.
25. A lactic acid bacterium according to claim 22 wherein the suppressor is one suppressing a nonsense mutation which in the absence of a nonsense suppressor capable of suppressing  
10 the mutation, confers auxotrophy.
26. A lactic acid bacterium according to claim 25 wherein the nonsense mutation is in a gene involved in the synthesis of pyrimidine nucleotides.
27. A lactic acid bacterium according to claim 26 wherein the  
15 nonsense mutation is in a *pyr* gene.
28. A lactic acid bacterium according to claim 22 which is selected from the group consisting of a *Lactococcus* sp., *Streptococcus* sp., *Lactobacillus* sp., *Leuconostoc* sp., *Pedio-*  
*coccus* sp. and *Bifidobacterium* sp.
- 20 29. A lactic acid bacterium according to claim 28 which is *Lactococcus lactis*.
30. A lactic acid bacterium according to claim 29 which is *Lactococcus lactis* subsp. *lactis* strain FA4-1-1 containing pFG100, deposited under the accession No. DSM 12091 or *Lacto-*  
25 *coccus lactis* subsp. *lactis* strain CHCC4146 containing pFG200, deposited under the accession No. DSM 12108.
31. A lactic acid bacterium according to claim 22 wherein the vector is stably maintained for at least 35 generations when it is cultivated in a medium not containing pyrimidine  
30 sources.



32. An isolated pure culture of a lactic acid bacterium according to any of claims 22-31.

33. A composition comprising an isolated pure culture of a lactic acid bacterium as defined in claim 32, and a carrier.

5 34. A composition according to claim 33 containing at least  $10^5$  colony forming units of the lactic acid bacterium per g.

35. Use of a composition as defined in claim 33 as a starter culture in the preparation of a product selected from the group consisting of a starter distillate, a product for  
10 cheese flavouring, a food product and a feed product.

36. A method of stably maintaining a vector according to claim 1 in lactic acid bacterial host cells growing in a particular environment, comprising providing said host cells as nonsense mutant cells having lost the capability of grow-  
15 ing in said environment, and transformed with the vector according to claim 1 containing a nonsense suppressor gene encoding a gene product restoring the capability of the nonsense mutant cells to grow in said environment whereby, if the vector is lost from the lactic acid bacterial cells, the  
20 cells will not grow.

37. A method according to claim 36 wherein the nonsense mutant cells having lost the capability to grow are auxothrophic cells.

25 38. A method according to claim 37 wherein the nonsense mutant cells have a mutation in a gene involved in the synthesis of nucleotides.

39. A method according to claim 38 wherein the lactic acid bacterial host cells are *pyr* mutants.

30 40. A method according to claim 36 wherein the environment is a material selected from the group consisting of milk, a



vegetable material, a meat product, a must, a fruit juice, a wine, a dough and a batter.



## ABSTRACT

Novel food-grade cloning vectors comprising a nonsense mutation suppressor-encoding gene, which vector, when it is present in a lactic acid bacterial strain, permits such a strain to have an industrially appropriate growth rate and metabolic activity. The cloning vectors are useful when present in lactic acid bacteria used as starter cultures in the preparation of food or feed products, or a starter distillate.

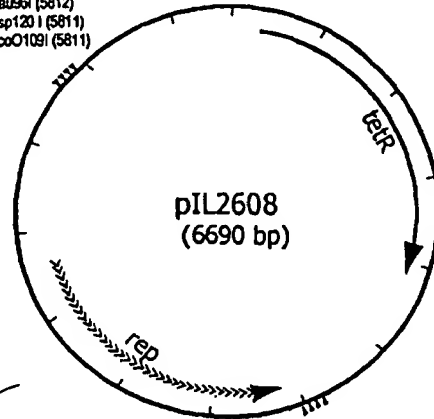


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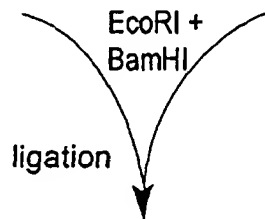
# *supD* PCR fragment

BamHI -35 -10  
 GGGATCCTTTAGGAAGCTAATTAACTATGGTATAATGAAATAGATAAGGGAGCGGAG  
 amber-4 >> *apD*  
 61 CCATGGCAGAGTGGTAATGCAACGGACTCTAAATCCGCGAACCGGTGTAAGCGCGGCAG  
 121 GGGTTCAAATCCCCTTGACTCCTTATAAGTAGAGTCTTTATTCTCAACTCTATTATATA  
 181 AGAAAAATGATAGTATTGAATACGCTTACTCTTTCTCTCTGTATGTATAAGATTACAT  
 EcoRI  
 241 CAGGAGGTTTTTTTATTCAAATATTCAGGTTCCATATTCATTAAATCAATATCAATTC  
 << amber-3

BamHI (5871)  
 Aval (5865)  
 SmaI (5865)  
 XmaI (5865)  
 PstI (5859)  
 EcoRI (5853)  
 HindIII (5826)  
 SalI (5826)  
 Aval (5820)  
 XhoI (5820)  
 Sau96I (5812)  
 Bsp120I (5811)  
 EcoO109I (5811)



BamHI (3007)  
 SpeI (3013)  
 XbaI (3019)  
 NotI (3025)  
 EagI (3025)  
 BstXI (3032)  
 SacII (3035)  
 BpmI (3046)



KpnI ApeI  
 Acc65I XhoI SalI HindIII EcoRI  
 GGTACCGGGCCCCCTCGAGGTCGACGGTATCGATAAGCTTGATATCGAATTC  
 BamHI SpeI XbaI NotI BstXI SacII BpmI  
 GGATCCACTAGTTCTAGAGCGGCCGCCACCGCGGTGGAGCTCCAGC  
 EcoRI  
 Ec113611

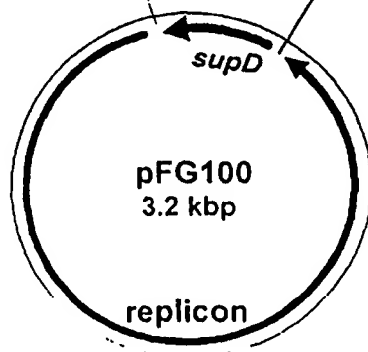


Fig. 1



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## Growth of strains harboring pFG1.1 and pFG100

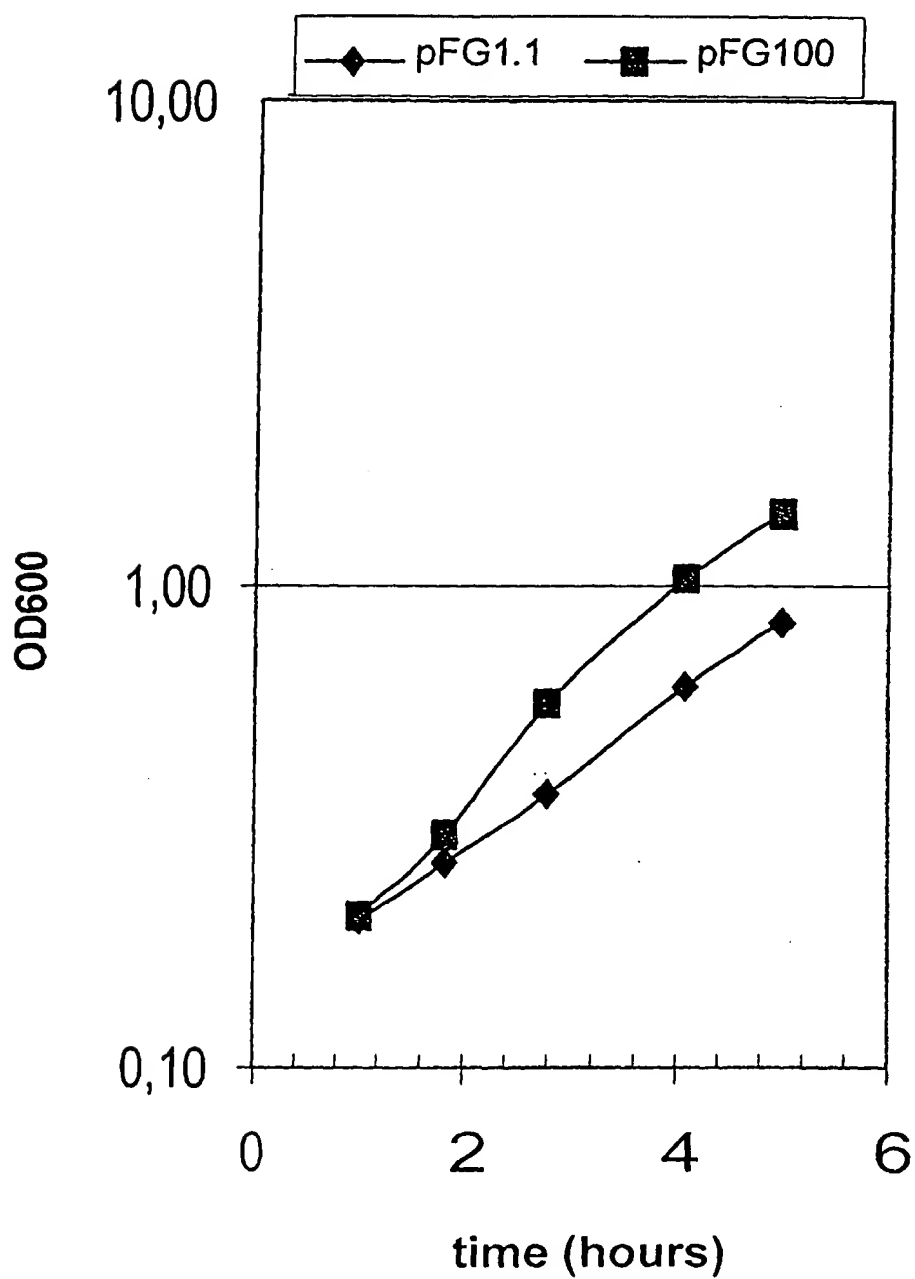
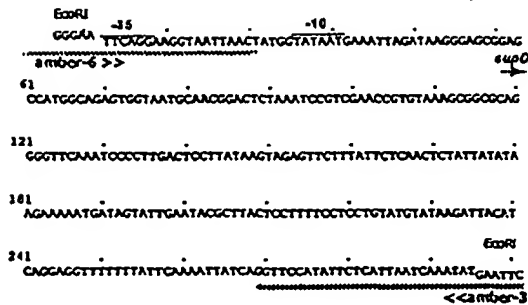
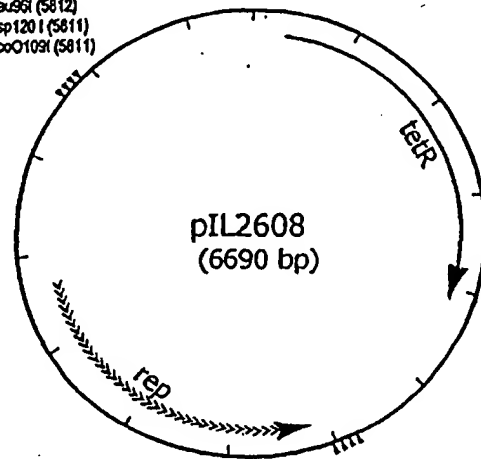
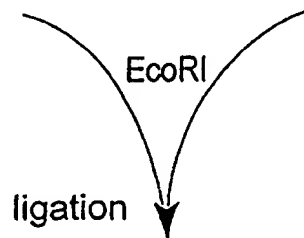


Fig. 2



*supD* PCR fragment

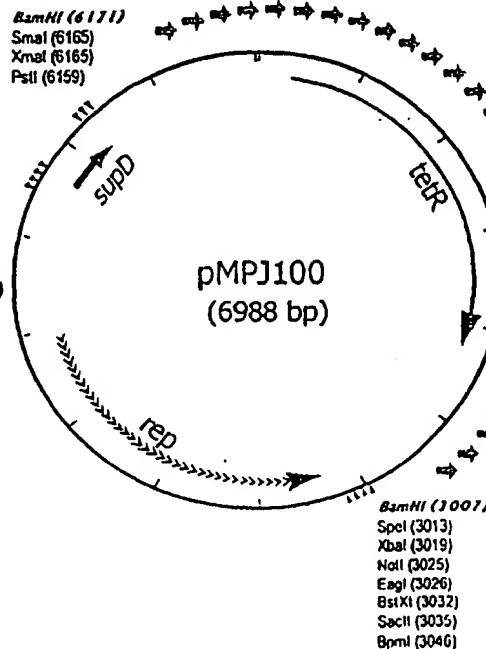
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 AatI (5865)  
 SmaI (5865)  
 XmaI (5865)  
 PstI (5859)  
 EcoRI (5853)  
 HindII (5826)  
 SalI (5826)  
 AatI (5820)  
 XhoI (5820)  
 Sau96I (5812)  
 Bsp120I (5811)  
 EcoO109I (5811)



BamHI (3007)  
 SpeI (3013)  
 XbaI (3019)  
 NotI (3025)  
 EagI (3026)  
 BstXI (3032)  
 SacII (3035)  
 BpmI (3046)

BamHI (6171)  
 SmaI (6165)  
 XmaI (6165)  
 PstI (6159)

HindII (5826)  
 SalI (5826)  
 XhoI (5820)  
 Sau96I (5812)  
 Bsp120I (5811)  
 EcoO109I (5811)



BamHI + religation  
 removes non food-grade part  
 and generates pFG101

Fig. 3



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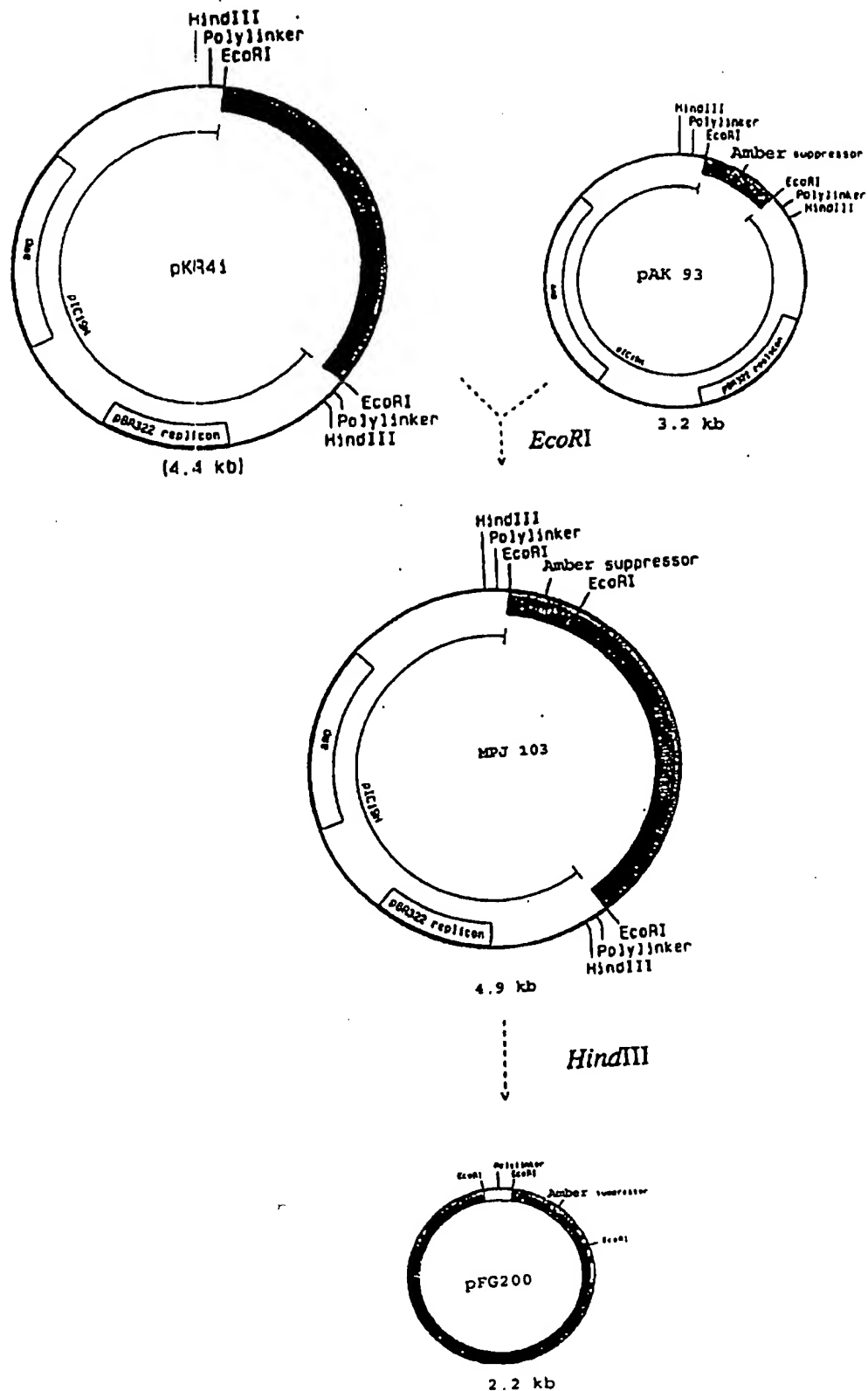


Fig. 4



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1 TGATTTATTATTAGCTAAAATTACTGACAGCCTGTTAATCATTCTGTGTCAGTAAATGC 60  
61 GACCAAAGCGAGCATTTTATCCATAGCTAAAAGAATTGTGACGGAGCTGATAATTCTCT 120  
121 CGTTCGTTAGCGACCAAAGCGAGCATTTTATGGATAGCTAAAAGAATTGTCATCAAAGCT 160  
181 GATAATTCTGTCTTAATATTTAGAAAAAGGAAGTAGAAAAAATGCAAGAAAATAGACC 240

M Q E N R P -

241 TGTCATTGCCCTTGATTCCCTGAATTCTCAGACGTAAAAGATTTTCTCGAAAAATTTGA 300

V I A L D F P E F S D V K D F L E K F D -

301 CCCGTCAGAACCAATTGTATATTAAGCTAGGAATGGAACCTTTTTACACGGCTGGGCCCA 360

P S E Q L Y I K L G H E L F Y T A G P Q -

361 AGTCGTTTACTATGTAAATCGCTCGGCCACAGTGATTCTTGAATTTAAACTCCATGA 420

V V Y Y V K S L G H S V F L D L K L H D -

421 TATTCAAACACCGTTGAATCCTCAATGCGTGTTTTAGCACGTTTGGGATTGGATATGGT 480

I P N T V E S S M R V L A R L G L D M V -

481 TAATGTTACGCCCGCTGGTGGTGTGAAATGATGGTTGCAGCTAAACGCGTTTAGAGGC 540

N V H A A G G V E M H V A A K R G L E A -

541 TGAACGCCAGTTGGACGGCAAAGGCCAAAATTAATTGCGGTCACACAATTAACCTCAAC 600

G T P V G R Q R P K L I A V T Q L T S T -

601 TTCTGAGAAAATTATGCAAAATGACCAAAAATTATGACTAGTCTTGAAGAATCGGTTAT 660

S E K I M Q N D Q K I M T S L E E S V I -

661 TAATTACGCACAAAAAACCCTCAAGCAGGACTTGACGGTGTGTTTGTTCGGCACATGA 720

N Y A Q K T A Q A G L D G V V C S A H E -

721 AGTTGAAAAAATTAAGCAGCGCATCGAAAGAATTCATTTGTCTCACACCAGGAATTCG 780

V E K I K A A T S K E F I C L T P G I R -

781 CCCAGAAGGTGCAAGTAAAGCGACCAAAAACGAGTAATGACACCTAAAGAAGCAAGAAC 840

P E G A S K G D Q K R V M T P K E A R T -

841 AATTGGTTCAGATTATATTGTTGTCGGCCGTCCAATTACCCAAGCAAAAGATCCAGTAGC 900

I G S D Y I V V G R P I T Q A K D P V A -

901 TAGCTATCATGCGATAAAAGCAGAATGGAATCAATAA 937

S Y H A I K A E W N Q \*

Fig. 5



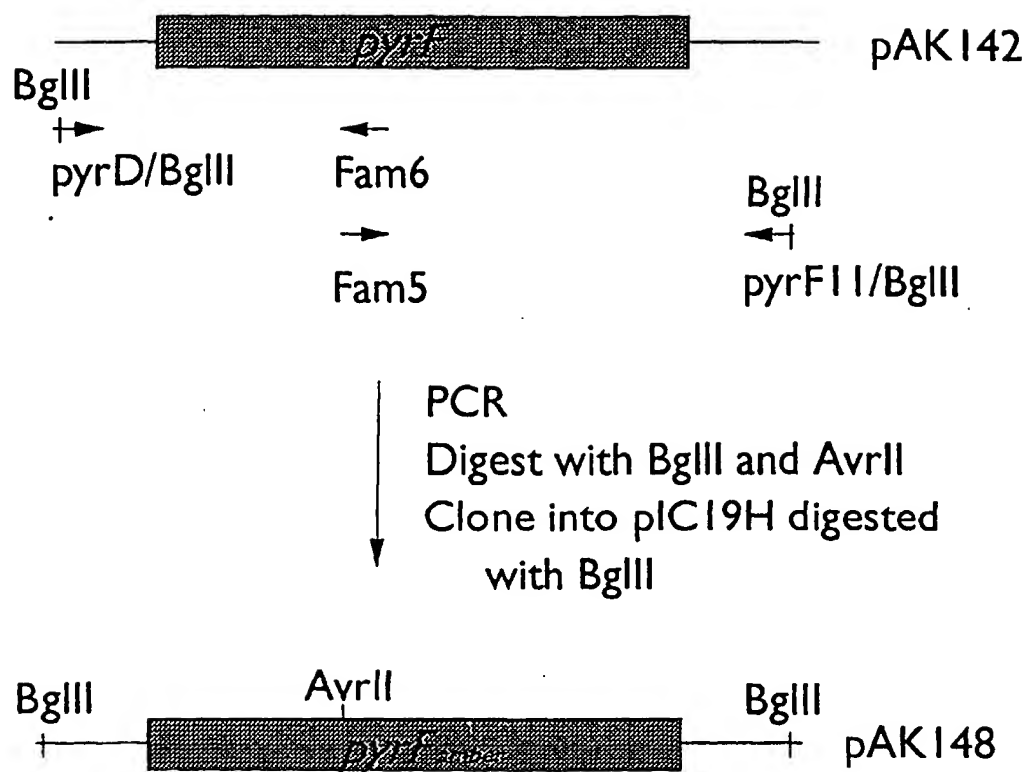


Fig. 6



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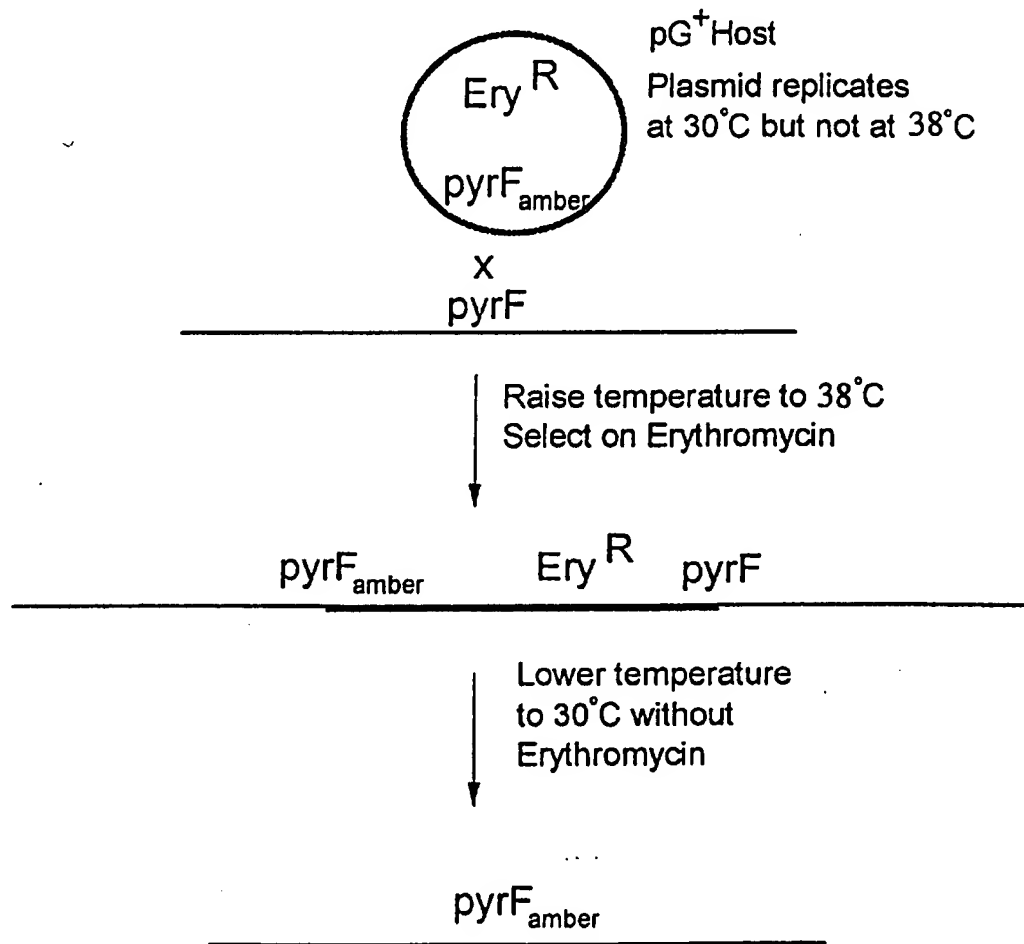


Fig. 7



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14 : (pH) FHCY-1 mlk  
16 : (pH) CHCC4171 mlk

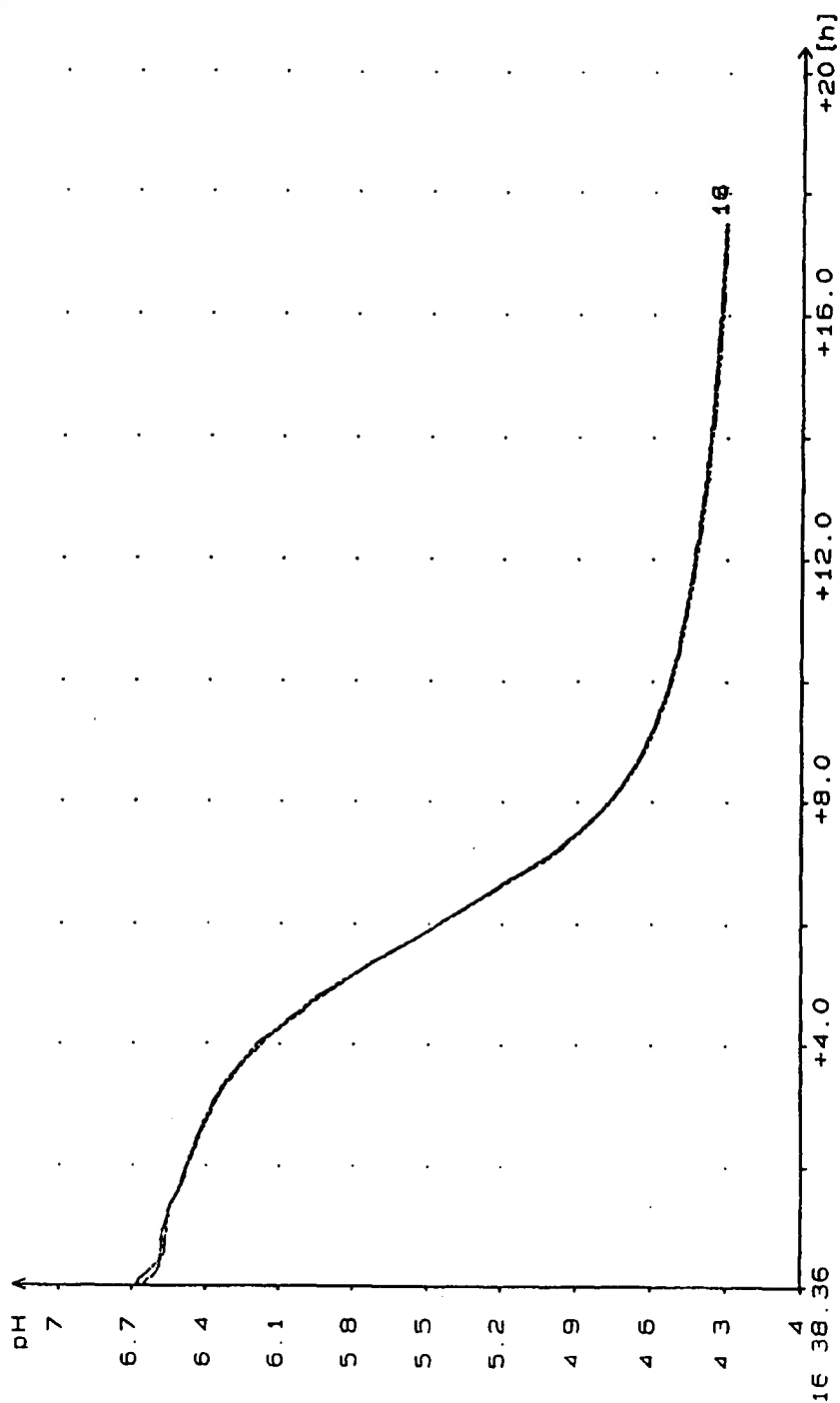


Fig. 8